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Converting Forest Residue to Structural Flakeboard - The Fingerling Concept

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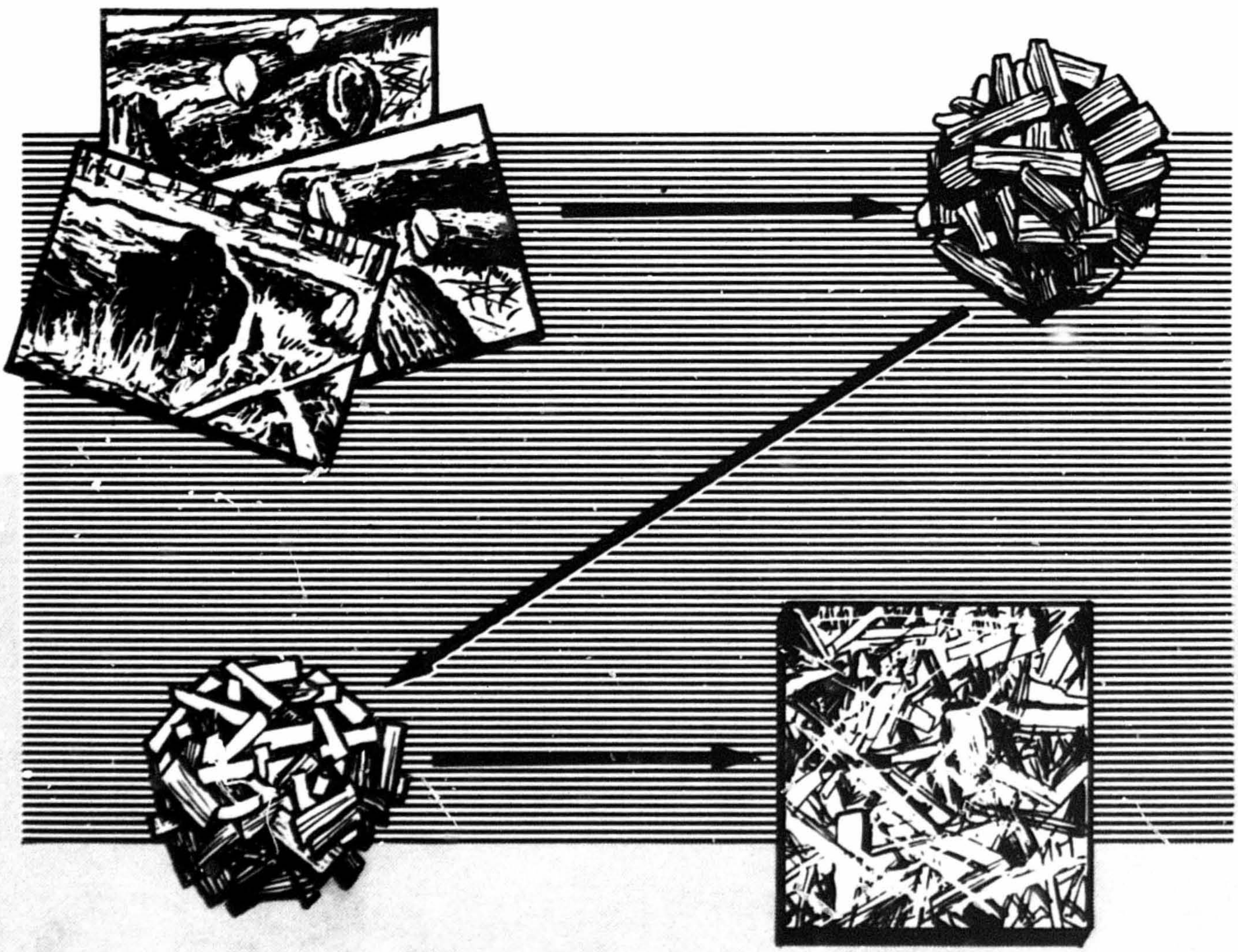

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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RESEARCH SUMMARY

Structural-grade flakeboard experimentally manufactured from forest residues showed mean strengths above 5,500 psi and stiffness (MOE) above 600,000 psi. For economical transport, residues are chipped into "fingerlings" in the woods. Chipping rates are estimated at 50 tons per hour for large residues, and 15 tons per hour for small residues--using different machines. Depending on the harvesting system selected, estimated costs of fingerlings delivered to the mill range from $25 to $33 per bone-dry ton for systems other than cable yarders.

STRUCTURAL FLAKEBOARD RESEARCH AND DEVELOPMENT PROGRAM

More intensive use of forest residue has long been the goal of forest managers. An estimated 9 billion cubic feet of residue is left in the woods annually. Of this amount, an estimated 6 billion cubic feet could be converted to particleboard, flakeboard, pulp, fuel, and other uses. Increased use of residues would greatly extend the timber supply and generally improve forest management.

Converting forest residues to structural-grade flakeboard has been under consideration for many years. However, several problems remained unsolved. The flaking machines available were designed for use at mills and were too cumbersome and too easily knocked out of tolerance to be used at logging sites. Residues other than cull logs were too bulky to haul to the mills economically. Trucks would overflow with small, crooked stems, limbs, and chunks when loaded to only a small fraction of weight capacity.

A concept that had shown promise in the laboratory was the breaking of residues into small pieces called "fingerlings," then flaking the fingerlings with a small laboratory flaking machine, and finally manufacturing the flakes into flakeboard. Theoretically, reside could be converted to fingerlings on the logging site and transported to the mill much more economically than the raw residues. Whether the fingerling concept would work on a commercial scale remained to be tested.

Early in 1973, the Forest Service began a research and development program to convert residues into structural flakeboard. Three Experiment Stations, four Divisions of the Washington Office, and the Forest Products Laboratory were involved (fig. 1).

FOREST SERVICE R & D PROGRAM -- STRUCTURAL FLAKEBOARD FROM FOREST RESIDUES

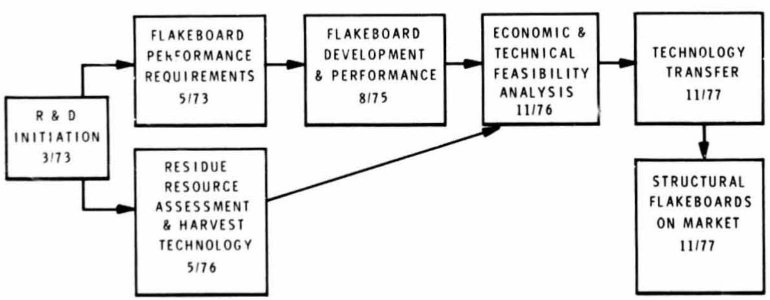

Figure 1.--Forest Service program to develop structural flakeboard from forest residue.

The Intermountain Station was to develop systems for harvesting western softwoods. The North Central Station was to develop machinery that could convert residues to fingerlings. The Forest Products Laboratory was to work out techniques for manufacturing flakeboard from fingerlings.

This report covers progress in the research and development program through the Flakeboard Development and Performance phase shown in figure 1. The report describes fingerling production from large and small residues, systems and costs for harvesting residues, the manufacturing of structural flakeboard, and configuration and performance of experimental panels.

THE FINGERLING CONCEPT

A fingerling is a piece of wood approximately 2 to 3 inches long, with a cross section of less than 1 by 1 inch (fig. 2). Fingerling production is the first step in producing flakes for structural flakeboard. The first flakes used for structural flakeboard were manually split from blocks 2.5 inches long. Later experiments used laboratory disk flakers to produce flakes.

Figure 2.--Fingerlings: the first step in converting residue to flakeboard.

The Research and Development (R&D) team recognized early the need for mechanization of fingerling and flake production. Different size classes of residue by geographical sections of the country suggested that the problem of reducing residues to fingerling chips be split for research assignment. The North Central Station pursued the problem of chippping the smaller residues, while the Forest Products Laboratory sought out equipment for chipping larger residues.

Small Residue

The North Central Station found that conventional chippers produced chips that varied too much in length to make suitable fingerlings. This led to the invention of a spiral head chipper (fig. 3). Although this machine would cut 95 percent or more of the pieces to the length set by the cutter, many exceeded the 1- by 1-inch cross section required for fingerlings. A hammermill with the grates removed reduced the oversized pieces to finger-sized particles in one pass. The structural flakeboard made from the aspen and spruce had very good strength (Erickson 1976).

The similar problem of oversized fingerlings occurred when lodgepole pine, Douglas-fir, and larch were chipped for this study. Hammermilling was needed to reduce chips to fingerling size. Redesigning the blades in the spiral head chipper may eliminate the need for hammermilling.

Conventional drive-shaft-mounted strain-gaging methods were used to measure torque over cutting time and hence specific horsepower requirements by species. The western species chipped required slightly higher horsepowers than Michigan-cut wood based on specific gravities (table 1), perhaps because of the low moisture content of the western wood. Power requirements, although a little higher than with conventional chippers,

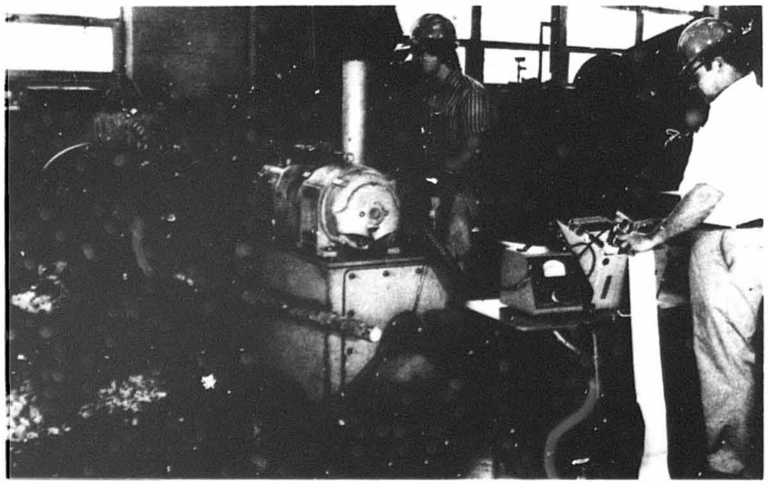

Figure 3.--Fingerling production using the spiral head chipper.

Table 1.--*Power requirements for producing fingerling chips with the Forest Service spiral head chipper*

Species	No. sample	Specific gravity	Specific power $\frac{Hp/min}{ft^3}$
Lodgepole pine	12	0.413 - 0.466	8.7
Douglas-fir	1	-	8.1
Larch	8	.492 - .515	9.2
Aspen	8	.343 - .377	5.2
Basswood	7	.278 - .318	5.2
Red oak	6	.510 - .549	9.3
Sugar maple	3	.618 - .658	15.1

could be met by portable units. Envisioned are field operations similar to whole-tree chipping operations now commonly producing pulpwood chips.

A conceptual field unit is shown in figure 4. A portable unit can be constructed for an estimated $35,000. Using a 6-year life, straight-line depreciation, and 15 percent interest and contingency rates, the hourly operating cost is estimated at $12.48. Based on an average 6-inch-diameter log and 60 percent feed rate, production is estimated to be 15 tons per hour (table 2).

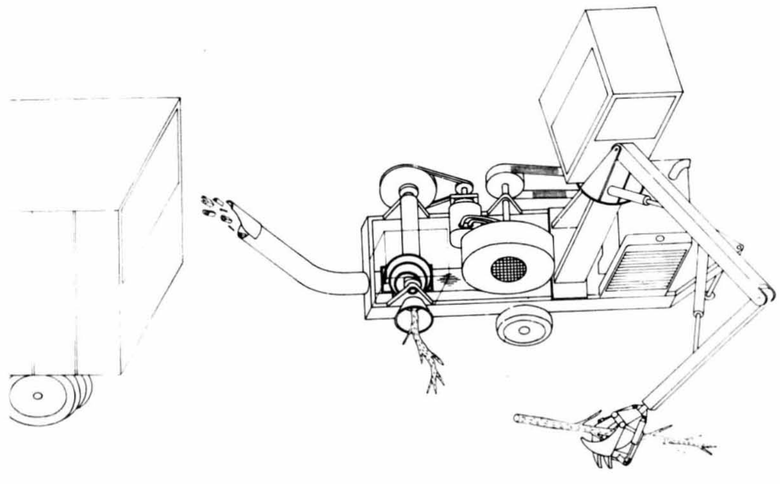

Figure 4.--Concept of mobile unit for producing fingerlings.

Table 2.--*Fingerling production by operating speed and log diameter*

Log diameter (inches)	Cutter head R/min 300	350	400
	Cubic feet per minute		
4	5.5	6.5	7.5
6	12.0	14.0	16.0
8	21.5	25.0	28.5
10	34.0	40.0	46.0

Large Residue

The Arasmith Manufacturing Company drum chipper was chosen for chipping large residues. A contract resulted in a modified drum chipper with special knives to cut chips 2 1/2 inches long (fig. 5). This chipping process required cutting the residues to the length of the drum and feeding the log axially parallel to the axis of the drum. The primary drawback is having to cut residues to a specified length. The principal advantage is that when chips are cut parallel to the axis of the log, horsepower consumption is not highly sensitive to log diameter. When the knives cut through the diameter of the log, large horsepowers are needed for larger logs because the cutting power increased proportional to the square of the log diameter. The modest horsepower required by the drum chipper will allow use of relatively low-powered units suited to in-the-woods chipping. The manufacturer estimates that a 42-inch-diameter, 60-inch-long drum chipper making 3/8-inch-thick fingerlings can be driven with a 200-hp diesel engine. Its output could be about 50 tons per hour of operation when fully loaded.

Figure 5.--Modified drum chipper.

HARVESTING SYSTEMS FOR RESIDUE

Research suggests that the most efficient time to harvest logging residue is in conjunction with the commercial harvesting, especially when clearcutting, because the entire tree can usually be removed in one operation. An alternative method is to remove part or all of the residue after commercial harvesting.

Previous studies of clearcutting in gentle terrain and near-complete removal of the fiber indicate that this method will be most economical for residue harvesting. This is true, of course, for almost any harvesting method comparisons.

Methods and Equipment

Figure 6 shows six systems for near-complete harvesting of relatively small-size timber averaging 10-ft^3 piece size. Equipment for each system is shown in figure 7. In a study of intensive utilization in lodgepole pine in Wyoming, merchantable and nonmerchantable (residue) volumes were nearly equal. (This probably represents a slightly less than normal volume of residue typical for lodgepole pine, but somewhat greater than normal for most other species in the Rocky Mountain West.)

Following is an example of the volume and classification of material from the Wyoming study (Gardner and Hann 1972). Description of unit 1 before and after harvesting:

Areas of unit (acres) - 16.8
Average stand age - 168.7
Average site index (50-yr base) - 43.7
Volume/acre to 6-inch top of live standing trees (ft^3) - 5,912
Volume/acre to 6-inch top of dead standing trees (ft^3) - 1,014
Total volume/acre to 6-inch top (ft^3) - 6,926 (±621)*
Volume/acre of tree residuals**(ft^3) - 1,124(±205)
Volume/acre of ground material ≤ 3 inches in size (ft^3) - 1,820(±308)
Preharvest total volume/acre of (ft^3) - 9,870(±723)
Postharvest volume/acre of ground material ≤ 3 inches (ft^3) - 564(±118)

* Figures in parentheses are 68-percent confidence intervals.
** Tree residuals are the difference between total volume for trees 3.0 inches d.b.h. and larger, and merchantable volume to a 6-inch top for trees 6.5 inches d.b.h. and larger.

Many combinations of equipment with different levels of mechanization could be designed for harvesting 10 ft^3 (total tree volume, merchantable and nonmerchantable) average timber size used in the simulation trials. Trials were therefore limited to tests of representative equipment types that would either singularly perform subsystem operations or combine them: felling, limbing, lopping, skidding, loading, hauling, felling-bunching, felling-skidding, limbing-lopping, felling-limbing-lopping-bunching. Other subsystem operations are performed as needed in each system shown in figure 7.

Because simulation does not produce an optimum system, the trials in this report are only to show possible methods of near-complete harvesting and their relative costs. A list of equipment for each operation and estimated production data are given in table 3. The special harvesting or processing equipment is shown in appendix A.

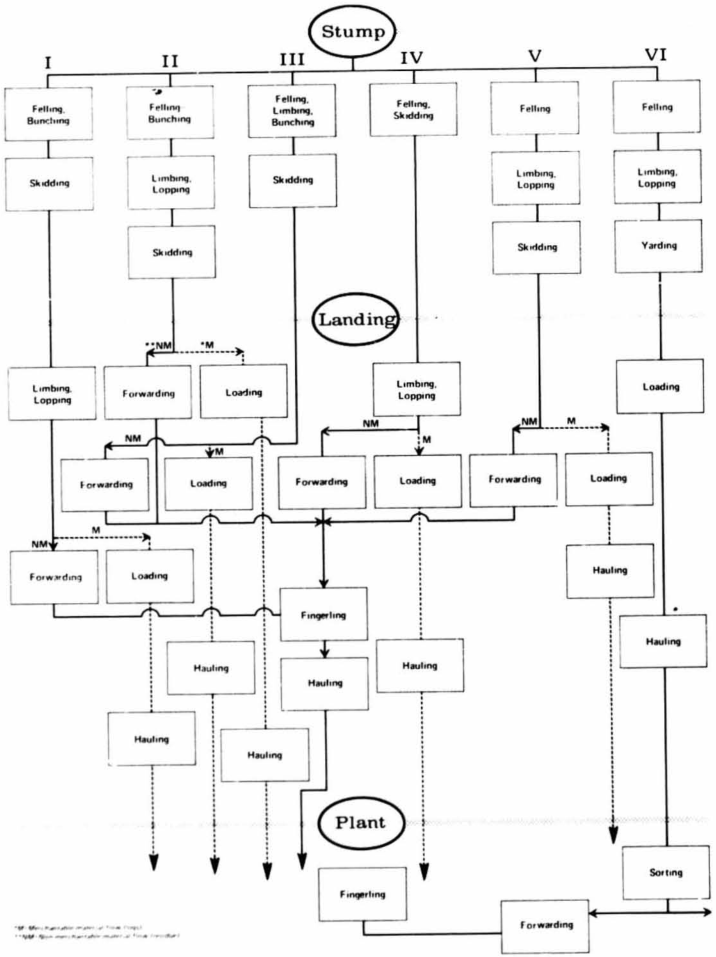

Figure 6.--Alternative near-complete harvesting systems.

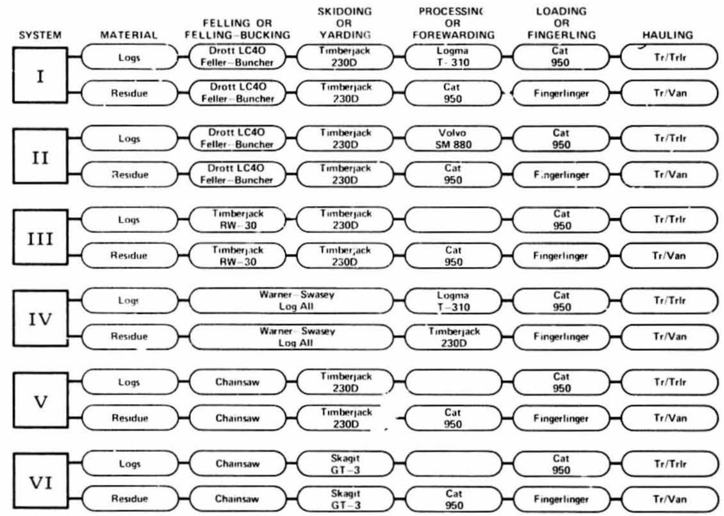

Figure 7.--Equipment for alternative harvesting systems.

Table 3.--*Operation, equipment type, and estimated production rates (piece size 10 ft^3, availability 75%; 40-mile haul)*

Operation	Equipment	Production rate
		Ft^3/h
Felling	Chainsaw	390
Limbing, bucking	Chainsaw	310
Felling, bunching	Drott Feller Buncher LC-40	1,480
Limbing, lopping	Volvo SM880 Processor	2,000
Limbing, lopping	Logma T-310	900
Skidding	Grapple Skidder Timberjack 230D	600
Yarding	Skagit Gt-3 Running Skyline	400
Loading	Front End-Cat 950	1,800
Loading	Knuckle Boom Drott LC-40	1,000
Forwarding	Front End Loader Cat 950	1,500
Chipping	Fingerling Chipper	600
Felling, limbing, bunching	Timberjack RW-30 Tree-length Harvester	500
Log hauling	Truck and trailer (6,000 m bd. ft)	320
Fingerling hauling	Truck and trailer (15 unit)	320
Felling, skidding	Warner-Swasey Log-All	200

In tables 4 through 9, the equipment and number of units needed to balance each system were tentatively designed for simulation trials. In every system, the harvested material is assumed to be a 50-50 mix of merchantable and residue material. For system VI, all of the harvested material is transported to the mill for sorting and the fingerlings are manufactured at the plant. For all other systems (fig. 7), the fingerlings are made at the landing and transported to the mill along with the merchantable logs. The logs and fingerlings are not necessarily transported to the same location, but for this report, they are transported the same distance: 40 miles.

Table 4.--*System I*

Operation	Equipment	No. units	Unit production	Total production
			------------Ft^3/h------------	
Felling, bunching	Drott Feller Buncher	1	1,500	1,500
Skidding	Timberjack 230D	3	600	1,800
Limbing, lopping	Logma T-310	2	900	1,800
(750 ft^3 residue)				
Forwarding	Cat 950	1	1,500	1,500
Fingerling		1	600	600
Hauling	Truck and trailer	2	320	640
(750 ft^3 merchantable)				
Loading	Cat 950	1	1,800	1,800
Hauling	Truck and trailer	2	320	640

Table 5.--*System II*

Operation	Equipment	No. units	Unit production	Total production
			------------Ft^3/h------------	
Felling, bunching	Drott Feller Buncher	1	1,500	1,500
Limbing, lopping, bunching	Volvo 880	1	2,000	2,000
Skidding	Timberjack 230D	3	600	1,800
(750 ft^3 residue)				
Fingerling		1	600	600
Hauling	Truck and trailer	2	320	640
(750 ft^3 merchantable)				
Loading	Cat 950	1	1,000	1,000
Hauling	Truck and trailer	2	320	640

Table 6.--*System III*

Operation	Equipment	No. units	Unit production	Total production
			Ft³/h	
Felling, limbing bunching	Timberjack RW-30 Tree-length Harvester	2	500	1,000
Skidding	Timberjack 230D	2	600	1,200
(500 ft³ residue)				
Forwarding	Cat 950	1	1,500	1,500
Fingerling		1	600	600
Hauling	Truck and trailer	2	320	640
(500 ft³ merchantable)				
Loading	Cat 950	1	1,800	1,800
Hauling	Truck and trailer	2	320	640

Table 7.--*System IV*

Operation	Equipment	No. units	Unit production	Total production
			Ft³/h	
Felling, skidding	Warner-Swasey	6	200	1,200
Limbing, lopping	Logma T-310	2	900	1,800
(600 ft³ residue)				
Forwarding	Timberjack 230D	1	1,500	1,500
Fingerling		1	600	600
Hauling	Truck and trailer	2	320	640
(600 ft³ merchantable)				
Loading	Cat 950	1	1,000	1,000
Hauling	Truck and trailer	2	320	640

Table 8.--*System V*

Operation	Equipment	No. units	Unit production	Total production
			Ft³/h	
Felling	Chainsaw	3	390	1,170
Limbing, lopping	Chainsaw	4	310	1,240
Skidding	Timberjack 230D	2	600	1,200
(600 ft³ residue)				
Forwarding	Timberjack 230D	1	1,500	1,500
Fingerling		1	600	600
Hauling	Truck and trailer	2	320	640
(600 ft³ merchantable)				
Loading	Knuckle Boom	1	1,000	1,000
Hauling	Truck and trailer	2	320	640

Table 9.--*System VI*

Operation	Equipment	No. units	Unit production	Total production
			Ft³/h	
Felling	Chainsaw	3	390	1,170
Limbing, lopping	Chainsaw	4	310	1,240
Yarding	Skagit GT-3	3	400	1,200
Loading	Knuckle Boom	1	1,000	1,000
Hauling	Truck and trailer	4	320	1,280
Sorting	Knuckle Boom	1	1,000	1,000
Forwarding	Cat 950	1	600	600
Fingerling		1	600	600

The approximate production rates in table 3 show relative production capacities and are for tentatively balancing the system. The best production data available are used for each simulation run. Published production data from the Pulp and Paper Research Institute of Canada (PPRIC) were used for most of the processors or harvesters. Other production data are from published or unpublished studies of the Forest Engineering research work unit at Bozeman, Montana.

Simulation

The simulation program (SAPLOS) used was developed by Leonard Johnson and others (1972). It was reprogramed from GASP II to GASP IV and adapted for more general use.

Table 10 presents the harvesting and transportation cost per cubic foot for each subsystem for merchantable and nonmerchantable material. The method for computing equipment operating cost for the simulation runs is shown in appendix B. The costs include delay time, but not nonproductive time or overhead cost.

Simulation is a technique to examine alternatives. Field operations could vary considerably from the simulation trials because of such factors as unfamiliarity with the system (in the short run), differences in equipment operators, conditions differing from those under which the data were deri.ed, and other variables. However, the trials are well within the accuracy needed to show the general viability of these systems for clearcut harvesting.

Harvesting systems I-IV are completely mechanized and are usable for the relatively flatter terrain in the Rocky Mountain area. Most of the material harvested with these systems would be lodgepole pine, which makes up 29 percent of the commercial species volume in the Northern Rocky Mountain area.

In table 11, the estimated delivered costs including nonproductive time and overhead are shown.

Table 10.--*Costs for simulated alternative harvesting systems* ($\$/ft^3$)

System	Material	Felling or felling and bucking	Skidding or yarding	Processing or forwarding	Loading or fingerling	Hauling	Subtotal	Total
I	Logs	0.0151	0.0291	0.0535	0.0706	0.1081	0.2763	0.4835
	Residue	.0151	.0300	.038[illegible]	.0614	.0623	.2072	
II	Logs	.0229	.0457	--	.0709	.1105	.2500	.5154
	Residue	.0229	.0457	.0581	.0731	.0656	.2654	
III	Logs	.0151	.0291	.0748	.0706	.1081	.2977	.5051
	Residue	.0151	.0300	.0384	.0616	.0623	.2074	
IV	Logs	0.1092		.0483	.0718	.1101	.3457	.6047
	Residue	.1092		.0253	.0618	.0627	.2590	
V	Logs	.0210	.0454	--	.0706	.1098	.2468	.5027
	Residue	.0210	.0441	.0531	.0731	.0646	.2559	
VI	Logs	.0210	.1575	--	.0709	.1100	.3594	.7118
	Residue	.0210	.1575	.0384	.0725	.0630	.3524	

Table 11.--*Delivered cost of fingerlings per dry ton for alternate harvesting systems (NPT = nonproductive time, OH = payroll cost.)*

System	$/dry ton (1973 cost)	Adj. 40% for NPT and OH	Adj. to 1975 cost
I	15.21	21.23	25.48
II	19.48	27.27	32.72
III	15.22	21.31	25.57
IV	19.01	26.61	31.93
V	18.78	26.39	31.67
VI	25.86	36.20	43.44

MANUFACTURING STRUCTURAL FLAKEBOARD FROM FINGERLINGS

Structural flakeboard is an exterior grade panel for use as construction sheathing and is one of the newer entries into the reconstituted wood panel products field. Generally, it is a panel whose surfaces are mainly composed of long, thin flakes (about 1.5 to 3.0 inches long and 0.020 inch thick) bonded together with a weather-resistant or highly durable resin.

Several years ago, researchers at the Forest Products Laboratory showed fingerlings would provide excellent furnish for ring flakers to produce the flakes for structural flakeboard (fig. 8, 9) Heebink and Dominick 1971; Heebink 1972).

Panel Performance Requirements

Structural flakeboard must have three key properties not required in particleboards commonly employed as furniture and floor underlayment: (1) durability, (2) dimensional stability in width and length, and (3) capability to carry building loads even under adverse environmental conditions. Common particleboards have been primarily designed as "gap fillers" or to have a smooth surface; hence, structural properties were not optimized.

Because weather resistance was not sought, conventional boards were constructed with urea resin, which is not as resistant to water or weather as the phenolic resin employed in exterior grades of plywood. Phenolic resin, or a similarly durable resin, should be employed in structural flakeboard.

Exterior-grade plywood meets or even exceeds the performance desired for sheathing. Although structural flakeboards meeting U.S. and Canadian standards are generally inferior in physical properties to structural plywood of equal thickness, phenolic flakeboards are being used as building sheathing, floor underlayment, and cladding (Canadian Standards Association 1975) in Canada. Canadian aspen flakeboard has recently been

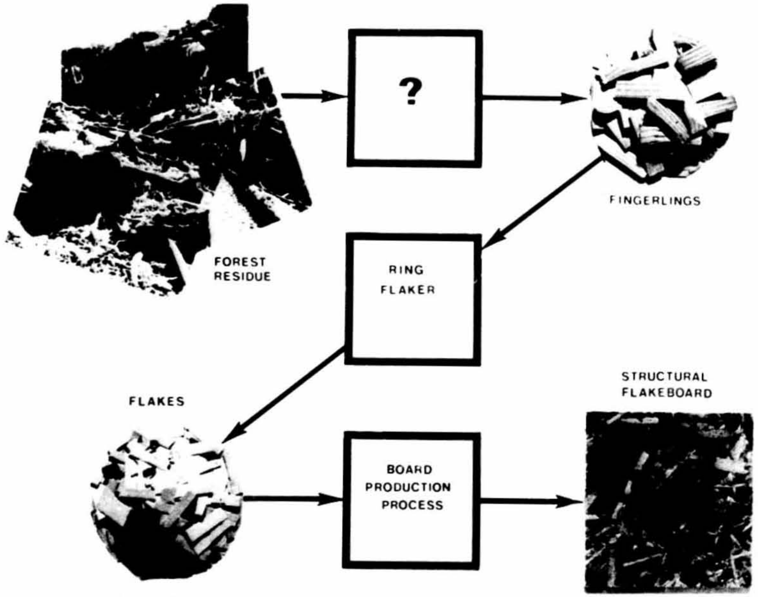

Figure 8.--Fingerling concept for converting forest residues to structural flakeboard.

Figure 9.--Fingerlings from spiral chipper, ring flakes, and board.

Table 12.--*Structural flakeboard requirements contained in United States and Canadian standards (minimum average values)*

Requirements	U.S.A.	Canada
Standard	CS 236-66	CSA 0188-1975
Type	2-B-2	Grade P & Q
Density (lb/ft^3)	37 to 50	Not specified or not applicable
Thickness tolerance (± in)	0.016	0.030 - 0.015
Modulus of rupture (lb/in^2)	2,500	2,000
Modulus of elasticity (lb/in^2)	450,000	400,000
Internal bond (lb/in^2)	60	40
Linear expansion (percent) (maximum average 50%-90% RH)	0.25	0.25
Screw-holding strength (lb)		
Face	250	Not specified
Edge	200	Not specified
Residual bending strength after accelerated aging (percent of initial)	50	50

considered suitable for roof and wall sheathing in the U.S. (HUD-FHA 1975). The U.S. standard (U.S. Department of Commerce 1966) does not specify end use for such boards, but the National Particleboard Association (1970) has obtained recognition of such properties for these panels to be used as decking (subfloor-underlayment combination) in mobile homes and factory-built housing. One U.S. manufacturer has obtained recognition of his product by the International Conference of Building Officials (ICBO 1972) as a satisfactory alternative material to that specified in the Uniform Building Code for roof, wall, and floor sheathing and underlayment. Hence, cities and States using the Uniform Building Code would allow use of this board in buildings. The Canadian and U.S. National Particleboard Association standards currently specifying physical property levels for structural flakeboards are shown in table 12. To guide the Forest Service Program, service load severity and panel properties (table 13) were established. A single structural flakeboard having an average MOE (modulus of elasticity) of 725,000 to 800,000 psi and near-minimum MOR (modulus of rupture) of 4,500 psi could meet load carrying requirements for equivalent thicknesses of plywood: the use of 5/8- to 3/4-inch single layer floor and 1/2-inch plywood roof sheathing is common (Countryman 1975).

Board Configurations

Defining the physical properties in structural panels poses the problem of selecting board configurations to meet requirements at reasonable or competitive cost. The Canadians have had excellent success with a panel composed of randomly oriented flakes, either placing the best quality flakes on the surface of the panel and mixed quality flakes in the core (three-layer random board) or simply randomly distributing mixed quality flakes throughout (homogeneous random board). Emplacing the highest quality flakes on the panel surfaces improves bending strength and stiffness. Further control of processing steps--controlling closure rate and pressure to densify surfaces, using minimum resin to attain desired strength, selecting the proper proportion of surface flakes to core material--improves random three-layer structural flakeboard panels (Ramaker and Lehmann 1976; Geimer and others 1975b).

Table 13.--*Selected performance goals for structural flakeboard*

Component	Thickness	MOE[1]	MOE[2]
	Inches	*Psi*	*Psi*
STATIC BENDING			
Floor	5/8	[3]800,000	4,000
16" c/c	3/4	475,000	3,000
Roofs	1/2	725,000	[3]4,500
24" c/c	5/8	375,000	3,000
Walls	5/16	500,000	2,500
16" c/c	3/8	300,000	2,200
RESIDUAL BENDING STRENGTH AFTER ACCELERATED AGING: 50 PERCENT OF INITIAL			
TENSILE STRENGTH PERPENDICULAR TO SURFACE (INTERNAL BOND)			
Strength--Dry		70 lb/in^2	
--After accelerated aging		35 lb/in^2	
DIMENSIONAL STABILITY (30 to 90 PERCENT RELATIVE HUMIDITY)			
Allowable linear expansion (in plane of panel)		0.25 percent	
Allowable thickness swelling		8 percent	
INTERLAMINAR SHEAR			
Strength		250 lb/in^2	
EDGEWISE SHEAR			
Strength		1,000 lb/in^2	

[1]Values are average values with a variability consideration.
[2]Values are near-minimum values.
[3]Values governing a single maximum performance panel.

Alining wood flakes or strands in one direction produces structural flakeboards of even higher strength and stiffness (Elmendorf 1965; Snodgrass and others 1973). To obtain adequate linear stability and strength in the nonalined direction, three-layer alined boards are suggested. The importance of this is reflected in figure 10, where expansion perpendicular to the alined direction can be very high unless restrained (Geimer and others 1975b). The cores consist of either random flakes or cross-alined flakes (Geimer, and others 1975a; Saunders and others 1975). (The alined panel patent (Elmendorf 1965) restricts commercial production of this panel type.) Typical surfaces of random and alined boards are shown in figure 11.

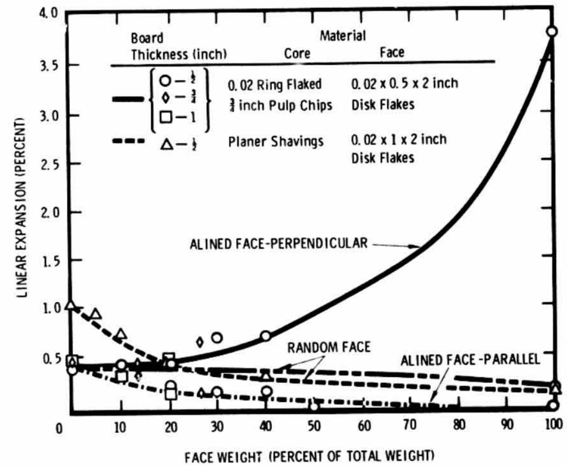

Figure 10.--Linear expansion of three-layer flakeboards after ovendry and vacuum pressure soak (Geimer and others 1975).

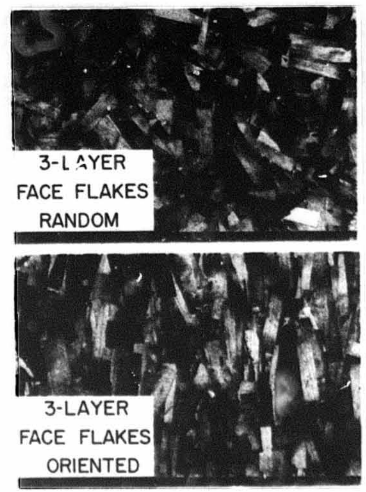

Figure 11.--Three-layer random surface and alined surface phenolic flakeboard constructions.

Table 14.--Comparative properties of various structural flakeboard configurations from disk and ring flakes

Flake type		Species[1]	Resin content	Dry specific gravity	Modulus of rupture	Modulus of elasticity	Internal bond	50-90 percent relative humidity: Linear expansion	50-90 percent relative humidity: Thickness swell
			Percent		Lb/in²	1,000 lb/in²	Lb/in²	Percent	Percent
		ALINED HOMOGENEOUS FLAKEBOARD							
Stands: 0.016 in by 1.5-3 in	--parallel	[2]VX	6	0.64	5,480	968	92	0.03	--
	--perpendicular				1,850	215		.40	
Ring flakes: 0.016 in by 1.5-3 in from large chips	--parallel	VX	6	.67	6,110	777	113	.04	--
	--perpendicular				2,250	254		.26	
Disk flakes: 0.020 in by 2 in by 0.05 in	--parallel	DF	5	.64	9,500	1,777	91	.00	9.4
	--perpendicular			.57	460	56		1.92	
		3-LAYER ALINED FLAKEBOARD							
Alined face--cross-alined core strands: 0.016 in by 1.5-3 in	--parallel	VX	5-6	.75	5,500	893	125	.11	--
	--perpendicular				4,000	445		.11	
Alined face--cross-alined core: Faces (30%): 0.02 by 2-in disk flakes	--parallel	DF	5	.65	6,580	1,398	112	.02	11.3
Core (70%): 1-in ring flakes from 1 in chips	--perpendicular			.63	3,110	412		.16	
Alined face--random core: Faces (40%): 0.02 by 2-in disk flakes	--parallel	DF	5	.65	6,740	1,394	110	--	--
Core (60%): 3/4-in ring flakes from 3/4-in chips	--perpendicular			.65	2,050	240		--	
Faces (30%): 0.02 by 2-in disk flakes	--parallel	DF	5	.72	6,620	1,247	86	.06	7.6
Core (70%): 0.02 by 2-in ring flakes from 2-in chips[2]	--perpendicular			.68	2,640	359		.28	
	--parallel	LP	5	.70	7,750	1,299	130	.10	8.7
	--perpendicular			.68	3,560	348		.35	
		3-LAYER RANDOM FLAKEBOARD							
Face flakes (30% bd wt): 0.02 by 2-in disk flakes plus 0.02 by 2-in ring flakes from 2-in chips (screened + 1/2-in) Core flakes (70 % bd wt): Above screened - 1/2-in		DF	5	0.65	4,620	700	125	0.04	8
Face flakes (50% bd wt): 0.02 by 2 ring from 2-in chips Core flakes: Slivers		LP	4/2	.67	5,255	795	100	--	--
Face flakes (30% bd wt): 0.02 by 2 disk flakes Core flakes (30% bd wt): 0.02 by 2 ring flakes from 2-in chips		DF	5	.72	5,260	754	117	.10	8.0
		LP	5	.69	5,270	710	152	.15	8.9
		RANDOM HOMOGENEOUS FLAKEBOARD							
Ring flakes: 0.02 by 2-in from 2-in chips		DF	5	.67	4,340	608	105	.05	11.5
Ring flakes: 0.02 by 2-in from 2-in chips		DF	3	.63	4,015	705	65	--	--
Disk flakes: 0.02 by 2-in from 2-in chips		DF	5	.66	4,310	691	36	.07	11.2
Ring flakes: 0.02 by 2-in from 2-in chips		LP	3	.59	4,935	745	75	--	--
Disk flakes: 0.02 by 2-in from 2-in chips		LP	3	.59	5,185	770	130	--	--

[1] Chips, hand-cut: about 1-by 1-by 2-in

[2] Species code: DF, Douglas-fir from west of Cascades; LP, lodgepole pine, VX, variety of softwoods.

Property levels that are attainable in various board configurations at equivalent board densities are given in table 14. Generally, strengths above 5,500 psi and stiffnesses (MOE) in excess of 750,000 psi are easily obtained for experimental panels having alined flake configurations. One must provide cross-alinement or random orientation of flakes in panels, however, to limit linear expansion. Three-layer random or homogeneous flakeboards here have mean strengths in the range of 4,000 to 5,300 psi, and stiffnesses (MOE) in the range of 600,000 psi to 800,000 psi. Linear expansion is controlled by random orientation of the flakes. Internal bond levels for all panel configurations can be sufficiently high to assure meeting requirements. These results show that structural flakeboards can be prepared from sound wood residues that meet commercial standards and Forest Service specifications.

Furnish Requirements

Furnish for structural flakeboard (especially surfaces) must consist of longer flakes or stands than are normally found in particles in conventional particleboards. Surface flakes should average 2 inches in length and 0.020 inch in thickness (Lehmann 1974; Saunders and others 1975; Snodgrass and Saunders 1974). Furnish for the core should also consist mostly of long flakes to enhance linear stability.

Flakes may be produced from fingerlings or directly from roundwood (fig. 12). The flakes resulting from these two techniques differ in quality, but both may be employed alone or in combination with each other to provide high performance structural flakeboards. Disk flakes from fingerlings are of lower quality than disk flakes produced from roundwood, but by alining fingerling-derived ring flakes in the board, one may attain high performance levels (Snodgrass and Saunders 1974).

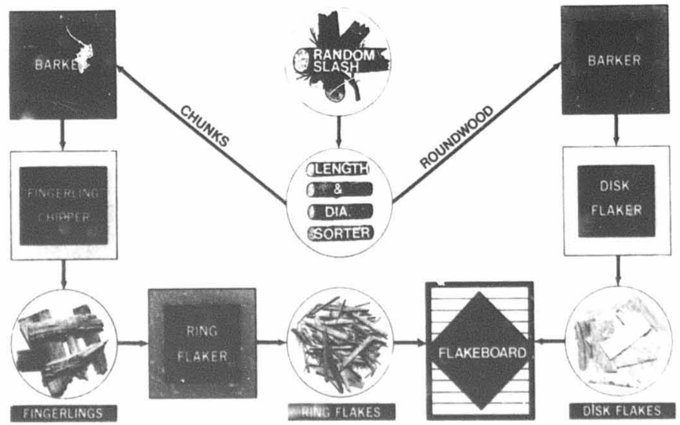

Figure 12.--Two parallel processing procedures for forest residue conversion into structural flakeboard.

Table 15.--*Comparative screen analyses of disk flakes (hammermilled) and ring flakes from unsound forest residue species. Ring flakes are derived from spiral or drum chipper fingerlings; disk flakes from split chunks. (Logs flaked when green except where noted.)*

Species	Percentage of material passing through 1/32-inch mesh screen: Ring flakes	Disk flakes (hammermilled)
	FROM SPIRAL CHIPPER FINGERLINGS	
Aspen	36	14
Paper birch	40	--
Western larch	24	14
Lodgepole pine	[illegible]	10
Lodgepole pine--dry logs	[illegible]	16
Douglas-fir	10	11
	FROM DRUM CHIPPER FINGERLINGS	
Douglas-fir (58 percent)--Western hemlock (42 percent)	30	21
Douglas-fir	39	21

Fingerling Chips for Flakes

Many of the experimental panels produced for evaluation in table 14 included ring flakes generated from hand-cut fingerlings. In order to assess the quality of flakes derived from "chipper" fingerlings, experiments were conducted employing partially decayed forest residues (Heebink and Chern;[2] Heebink, and others, in press).

Included species were Douglas-fir, western hemlock, lodgepole pine, western larch, aspen, and paper birch. Fingerlings from the spiral chipper and Arasmith drum chipper were flaked in a Pallmann ring flaker. Hand-cut chunks of similar material were disk-flaked and then hammermilled. Homogeneous panels were prepared from each furnish retained on 1/32-inch mesh screen. The percentages of fines passing through a 1/32-inch screen are given in table 15. Fines for the ring-flaked material were twice the hammer-milled, disk-flaked material. Normally, for sound wood, the proportion of fines in hammermilled, disk-flaked material passing a 1/32-inch screen is about 3 to 5 percent. The nearly 2 to 4 times the amount of fines generated here reflects the presence of barky or decayed wood and the influence of hammermilling.

Flaking decayed material produces proportionately smaller pieces than does flaking sound material, with the proportion of smaller flakes increasing with decreasing residue size. With sound wood (table 16), flake uniformity from disk and ring flakers is notably different. About 93 percent of disk-cut flakes are retained on a >1/4-inch screen, while only 56 percent of ring flakes from hand-cut fingerlings are retained (Lehmann and Geimer 1974).

[2] Heebink, B. G., and J. Chern. 1975. The "Spiral Chipper": evaluation of an initial reduction device to convert forest residues for structural particleboard. (Unpubl. FPL Off. Rep.)

Table 16.--*Comparative screen analyses of 0.20 inch thick disk flakes (nonhammermilled) and ring flakes produced from sound and decayed Douglas-fir forest residues (greater than 4 inches diameter) (Lehmann and Geimer 1974)*

Screen mesh (inches)	Mean screen fraction: Ring flakes from hand-cut fingerlings (Sound)	(Decayed)	Disk flakes (nonhammermilled) (Sound)	(Decayed)
	Percent			
>1/2	15.4	11.4	84.7	60.1
<1/2 >1/4	40.6	29.6	8.6	22.4
<1/4 >1/8	18.2	18.1	3.0	9.5
<1/8 >1/16	12.7	18.5	2.0	5.4
<1/16	13.2	22.4	1.7	2.6

Homogeneous random flakeboards were prepared employing 3 percent phenol-formaldehyde resin and 1 percent wax. The physical properties of the panels were evaluated and compared to assess the influence of flake type. Physical properties (before and after accelerated aging) are given in table 17. Distinct reductions in strength are evident when compared to similar panels produced from wholly sound wood (table 14), and again are attributable to lower wood quality used in panels shown in table 17. Levels for MOR, MOE, and IB (internal bond) for many panels still exceed current Canadian and American standards given in table 12.

Panels made from various kinds of flakes are compared in table 17. Ring-flake panels generally have reduced MOR and MOE levels compared to disk-flake panels, but IB is similar. Ring flaking hand-chipped fingerlings produces flakes that are inferior to those from disk flaking, but drum-chipped fingerlings induce a further reduction in ring flake quality (Heebink, and others, in press). Panel stiffness (MOE) again appears most sensitive to the difference in quality of ring flakes from hand-cut fingerling and drum-chipped fingerlings. No difference in linear expansion or thickness swell was detected between ring flakeboards and disk flakeboards.

To consistently obtain panels of maximum strength from ring flakes derived from forest residue, the flakes must be further separated during screening and the longest flakes placed in the panel surfaces.

Table 17.--*Mean strength properties for flakeboards of disk and ring flakes from forest residues containing decay.*

Species	Flake[1] type	Initial condition: Specific gravity[2]	Initial condition: Modulus of rupture[3]	Initial condition: Modulus of elasticity[3]	Initial condition: Internal bond	After accelerated aging: Modulus of rupture[3] (Based on thickness prior to accelerated aging)	After accelerated aging: Modulus of elasticity[3] (Based on thickness prior to accelerated aging)	After accelerated aging: Internal bone
Aspen	Disk	0.592	4,465	670	35	2,639	594	3
	Ring[4]	.576	2,682	443	35	1,834	368	3
Paper Birch	Disk	.589	2,156	426	38	1,332	243	3
	Ring[4]	.593	1,828	332	22	1,204	240	2
Western Larch	Disk	.585	2,375	335	45	1,332	192	14
	Ring[4]	.577	2,772	408	31	1,859	293	9
Douglas-fir	Disk	.608	4,119	543	74	2,880	438	25
	Ring[4]	.622	2,894	450	56	1,888	349	13
Douglas-fir	Disk	.595	2,744	503	53	1,776	342	21
	Ring[5]	.596	2,370	426	50	1,486	258	25
Douglas-fir(58%)	Disk	.595	3,339	487	46	2,992	505	28
Western hemlock (42%)	Ring[5]	.602	2,883	410	54	2,357	359	30
Lodgepole pine								
Dead	Disk	.578	4,034	594	32	2,908	485	19
	Ring[4]	.587	3,096	469	59	2,228	373	22
Green	Disk	.564	3,650	522	53	3,079	488	24
	Ring[4]	.590	3,173	486	73	2,635	463	10

[1] Disk flakes: Logs reduced to 2-in-thick disks--disks were reduced to flakes on a disk flaker.
[2] Specific gravity based on ovendry weight and volume at 65% relative humidity.
[3] Corrected to a common mean specific gravity.
[4] Ring flakes: Logs reduced to fingerlings on "spiral chipper." Fingerlings reduced to flakes on a ring flaker
[5] Ring flakes: Logs reduced to fingerlings on "drum chipper." Fingerlings reduced to flakes on a ring flaker.

SUMMARY

Residue harvesting for structural flakeboard furnish should be increasingly economically attractive as markets in the Rocky Mountain area develop, structural flakeboard prices increase, and residue harvesting costs fall. Theoretically, a fingerling chipper working with one of five proposed harvesting systems could deliver fingerlings to the flakeboard mill for $25 to $33 per bone-dry ton for systems other than cable yarders.

The conversion of residue to fingerlings at the logging site for simplified handling and hauling appears to be attractive technically and economically. A modified drum chipper and a spiral chipper can produce fingerlings in the woods or at the mill that can be further converted to ring flakes for alined-flake, or random-flake structural flakeboard that meets or exceeds commercial standards or Forest Service standards. Experimental alined-flake flakeboard made from fingerling-derived flakes achieved mean strengths above 5,500 psi and stiffnesses (MOE) above 750,000 psi. Mean strengths of random-flake panels were above 4,000 psi and stiffnesses (MOE) above 600,000 psi. Because fingerling-derived ring flakes are inferior to disk flakes, high-strength structural flakeboards should employ disk flakes, or else the longest ring flakes should be positioned in the board surface.

A modified drum chipper with a 200 hp engine was estimated to produce 3/8-inch-thick fingerlings from large diameter residue at a rate of 50 tons per hour. Smaller residue (1-9 in) can be reduced to fingerlings in a spiral chipper at an estimated rate of 15 tons per hour (60 percent feed rate).

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APPENDIX A

Special Equipment

The following section depicts (fig. 13-16) some of the special equipment involved in this study.

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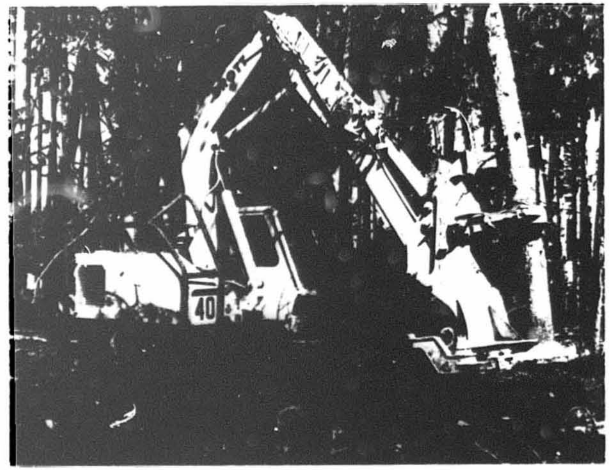

Figure 13.--Drott Feller-Buncher, Model 40 LC. The tree is severed at the base by the shear, and controlled for bunching by the locking arm.

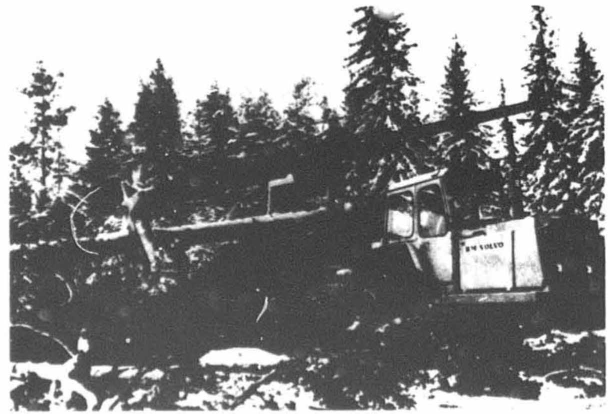

Figure 14.--BM Volvo SM-880 Processor. The felled tree is grappled and returned to the holding arm. On the return travel of the boom for the next tree, the tree in the holding arm is prelimbed by the knives on the edge of the grapple arms; the tree is then automatically transferred to the limber feed rolls and pulled through two wraparound, belt-type knives. The tree is topped by a circular saw.

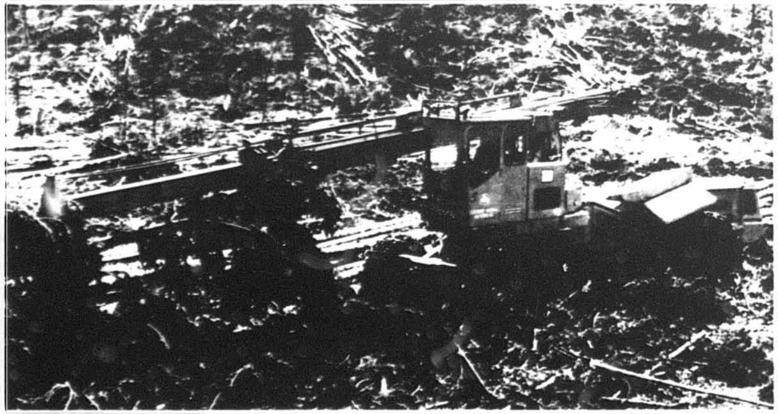

Figure 15.--Logma T-310 Limber-Buncher. Felled trees are grappled by the front set of limbing knives and drawn top first toward the machine. When the point of minimum top diameter is located under the rear set of knives, these grapple the tree and hold it while the top is sheared. With the rear set of knives holding the tree, the boom is extended and the front set of knives moves down the stem, removing the limbs.

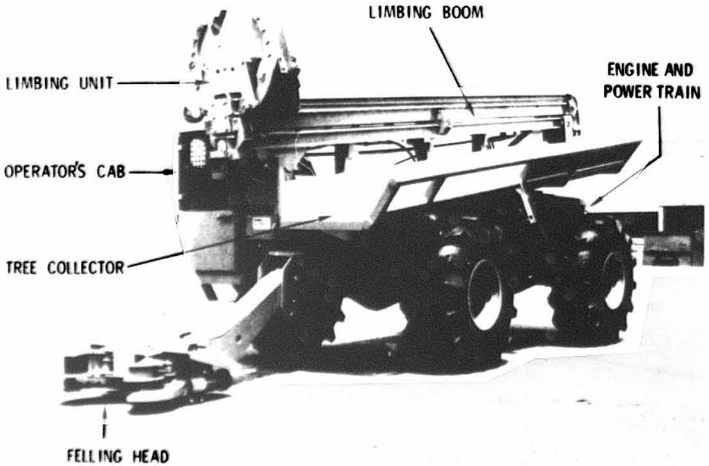

Figure 16.--Timberjack RW-30 tree-length harvester. Fells, limbs, bucks, and transports whole trees.

APPENDIX B

Operating Costs

When used to compare effectiveness of selected harvesting systems, cost must be computed uniformly. Cost computations differ among owners. Some use straight-line depreciation and others may use double declining balance or sum of years digits. Also, different allowances are made for repairs, maintenance, etc. The Equipment Data Sheet form attached (fig. 17) was used for all equipment in this report to provide for more meaningful comparisons. Tables (18 and 19) show equipment, operator, and crew cost.

EQUIPMENT DATA SHEET

Specifications

Mfg. ______________________________

Model ______________________________

Engine ______________________________

General Specs. ______________________________

____

Standard Costs

Est. Life (N) ______________

Est. Use/Yr. ______________

Purchase Cost & Fgt. (I) ______________

Sal. Value (S) ______________

Fixed	Ann.
Dep. $\frac{I-S}{N}$	______
Ave. Value of Invest. $\frac{I-S(N+1)}{2N}$ = ______	
10% AVI for Int., Ins., Tx. and Storage	______
Repairs and Maintenance (100% of Dep.)	______
Total Ann. Cost	______
Oper.	**Hour**
Fixed Costs ÷ Hours of Use	______
Fuel, Lub., etc.	______
Total Cost/Hr.	______

Figure 17.--Sample sheet for recording equipment data.

Table 18.--*Estimated equipment cost, 1975 prices.*

	Depreciation and Operation	Wages	Total
	Dollars		
Chainsaw	1.28	5.50	6.78
Warner-Swasey[1] Log All	16.63	7.80	24.43
Drott LC-40 Feller-Buncher	16.63	7.80	24.83
Volvo SM-880	32.34	7.80	40.14
Logma T-310	20.85	7.80	28.65
RTS Grapple Timberjack 230D	9.48	7.20	16.68
Skagit GT-3	79.14	7.80	86.94
Cat 950 Front End Loader	20.73	7.80	29.53
Fingerlinger	12.08	7.20	19.28
Tractor-trailer	12.28	7.20	19.48
Loader LC-40	16.63	7.80	24.43
Harvester Timberjack RW-30	18.71	7.80	26.51

[1] No longer available.

Table 19.--*Estimated crew cost, 1975 wages.*

	Wages		
	Base	>20% B&PR[1]	Total
	Dollars		
Heavy equipment operator	6.50	1.30	7.80
Light equipment operator	6.00	1.20	7.20
Choker setter	5.50	1.10	6.60
Knot Bumper	5.50	1.10	6.60
Rigger	5.50	1.10	6.60
Truck driver	6.00	1.20	7.20
Foreman	7.00	1.40	8.40

Skagit crew
- 1 Operator
- 1 Knot Bumper
- 2 Riggers (Trees are rigged ahead of logging sets.)
- 2 Choker Setters
- 6

[1] Benefits and payroll cost.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

Billings, Montana
Boise, Idaho
Bozeman, Montana (in cooperation with Montana State University)
Logan, Utah (in cooperation with Utah State University)
Missoula, Montana (in cooperation with University of Montana)
Moscow, Idaho (in cooperation with the University of Idaho)
Provo, Utah (in cooperation with Brigham Young University)
Reno, Nevada (in cooperation with the University of Nevada)

Gardner, Rulon B., Erwin L. Schaffer, and John R. Erickson.
1978. Converting forest residue to structural flakeboard--the fingerling concept. USDA For. Serv. Res. Pap. INT-200, 31 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Structural-grade flakeboard experimentally manufactured from forest residues showed mean strengths above 5,500 psi and stiffness (MOE) above 600,000 psi. For economical transport, residues are chipped into "fingerlings" in the woods.

KEYWORDS: residue, harvesting, structural flakeboard, fingerlings, flakes.

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